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SUMMARY

Potassium vapor was condensed inside the tubes of a horizontal, multitube heat exchanger. The tubes were cooled with the liquid metal sodium potassium (NaK) flowing in a countercurrent direction in the space surrounding the tubes. Steady-state data are presented to show the effects of NaK coolant inlet temperature and coolant flow rate on the condensing length, the coolant temperature profiles, and the overall pressure drop of the condenser over a range of potassium inlet temperatures from 1200° to 1500° F. A correlation of the overall pressure drop on the potassium side of the condenser was obtained by plotting the ratio of the measured overall pressure drop to the velocity head in the tube inlet as a function of the condensing-length-to-diameter ratio.

INTRODUCTION

Future exploration of space may require large amounts of electric power for propulsion systems, life-support systems, and operation of scientific experiments. One method of generating electric power is to drive an electric generator with a turbine in a Rankine power cycle. In this cycle, vapor is generated in a boiler, expanded through the turbine, and condensed in a condenser. The liquid condensate is then pumped back to the boiler and recirculated. The heat source for the system could be a nuclear reactor or a large solar collector. The waste heat of the cycle, the heat of condensation, must ultimately be rejected by radiation to space. Two heat-rejection systems are currently being considered: (1) the turbine outlet vapor is condensed directly in a radiator, and (2) the vapor is condensed in a small heat exchanger that is cooled by a fluid flowing through a radiator circuit (cooling loop). In either case, the radiator is a large, heavy component of the system. The temperature of the radiator fluid must be maintained at a high level in order to minimize radiator size. For this reason, the alkali metals (potassium, sodium, etc.) are being considered as fluids for both the working and the cooling loops. A current design (ref. 1) uses potassium for the working fluid with a turbine outlet temperature of about 1200° F. More advanced systems may operate at even higher temperature levels.

Heat-transfer coefficients for potassium vapor condensing inside a single NaK-cooled tube are reported in reference 2. Condensing heat-transfer coefficients between 10 000 and 100 000 Btu per hour per square foot per $^{\circ}$F were obtained over a range of vapor temperatures from 884° to 1414° F. Condensing data for mercury in single NaK-cooled tubes have been reported in references 3 and 4. Data with water as the working fluid are presented in references 5 and 6. Additional water data, along with an analytical study of annular flow condensing, are presented in reference 7.

In addition to these single-tube studies, it was considered necessary to have data on the performance of multitube condensers operating with the alkali metals as working fluids at temperatures in the range anticipated for space application of Rankine power systems. A facility was constructed (ref. 8) at the NASA Lewis Research Center to closely resemble a Rankine space-power system (except that the turbine was not included) in order to obtain such data. In this facility, potassium vapor was generated in a NaK-heated boiler at temperatures from 1200° to 1500° F with vapor qualities of 70 to 100 percent. The vapor could be condensed either in a direct condensing radiator or in a NaK-cooled heat exchanger (ref. 9). The thermal power level of the facility was 150 kilowatts.

In this investigation, potassium vapor was condensed in a seven-tube NaK-cooled counterflow heat-exchanger-type condenser. The primary objective of this study was to determine the variation of the condensing length, the heat-flux distribution, and the overall pressure drop of the condenser with changes in the independent variables. The independent variables affecting the condenser are vapor flow rate, vapor inlet temperature, coolant flow rate, and coolant inlet temperature. Data are presented over a range of potassium flow rates from 152 to 499 pounds per hour, potassium inlet temperatures from 1199° to 1500° F, coolant flow rates from 6.2×10^{3} to 29.9×10^{3} pounds per hour, and coolant inlet temperatures from 960° to 1407° F.

APPARATUS

Experimental Facility

The alkali metal facility (ref. 8) consisted of three independent fluid circuits: the heating loop, the working loop, and the cooling loop. A schematic flow diagram of the facility is shown in figure 1. The major components of the working loop were installed in a horizontal (and in essentially the same) plane to minimize the effect of gravity on

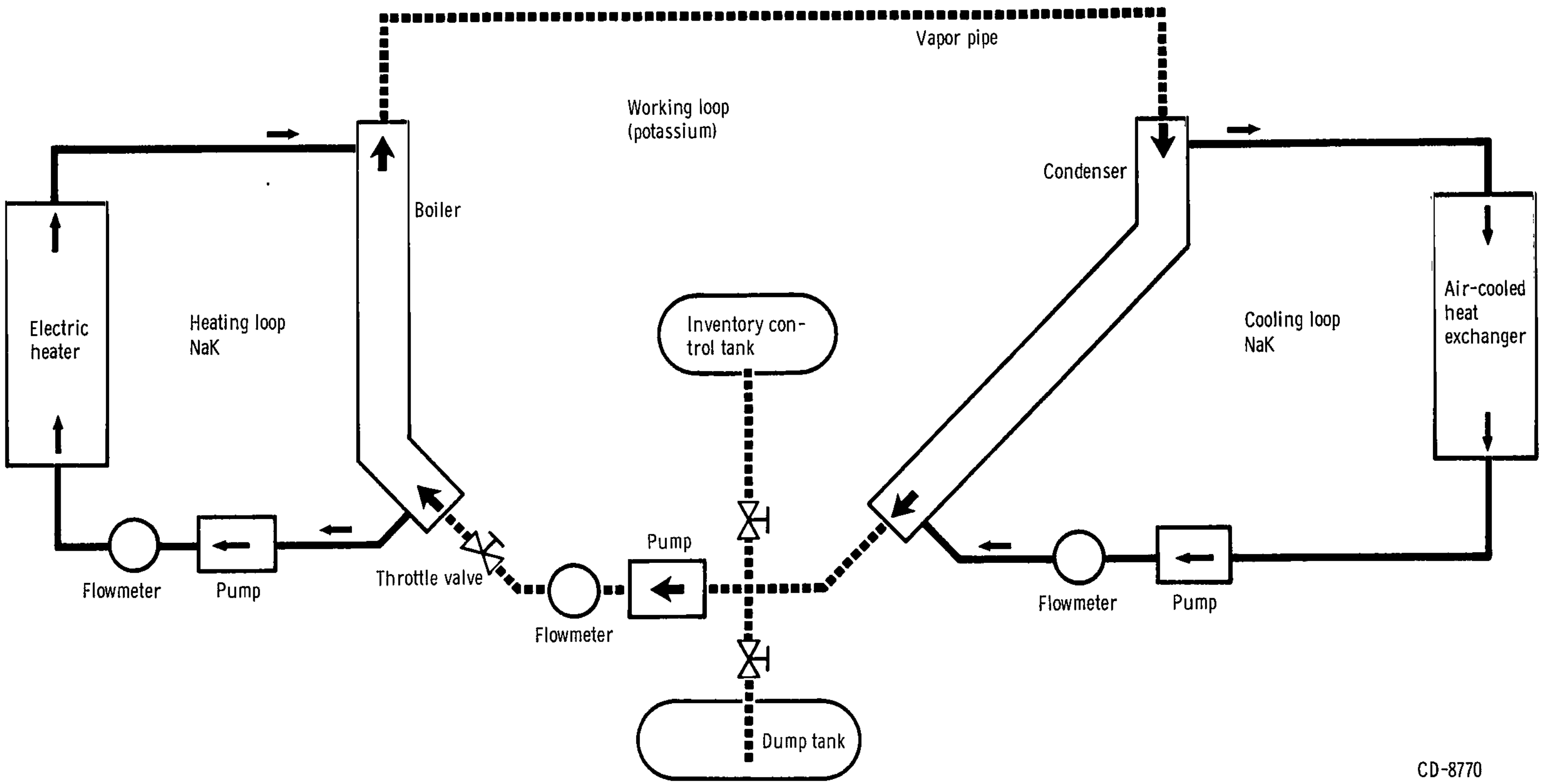


Figure 1. - Schematic flow diagram of facility.

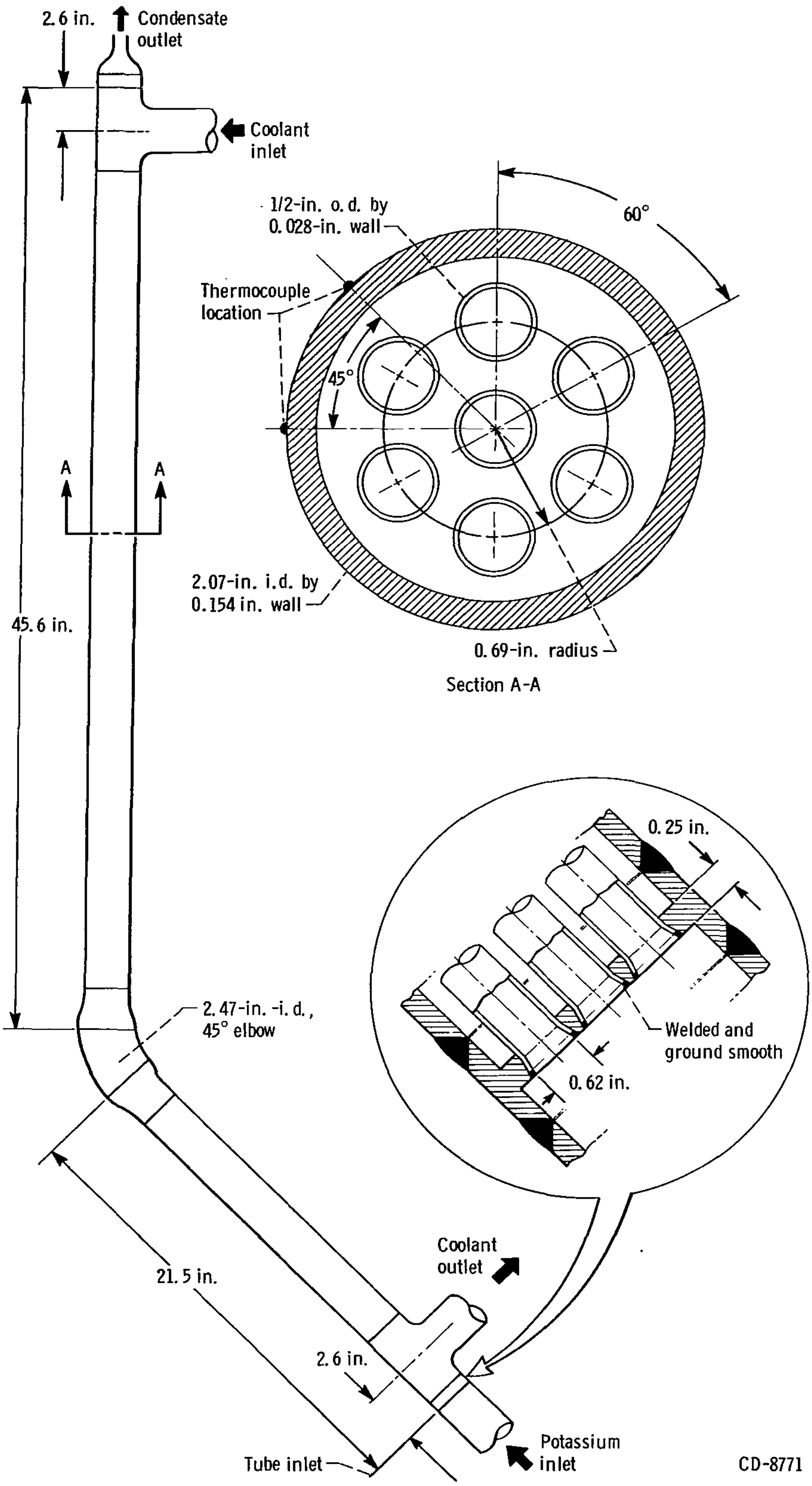


Figure 2. - Drawing of seven-tube potassium condenser.

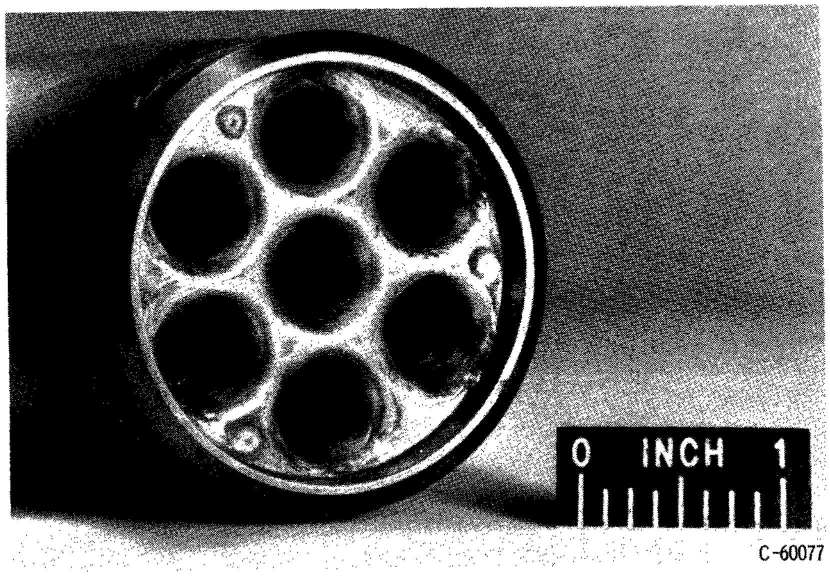


Figure 3. - Potassium inlet end of condenser.

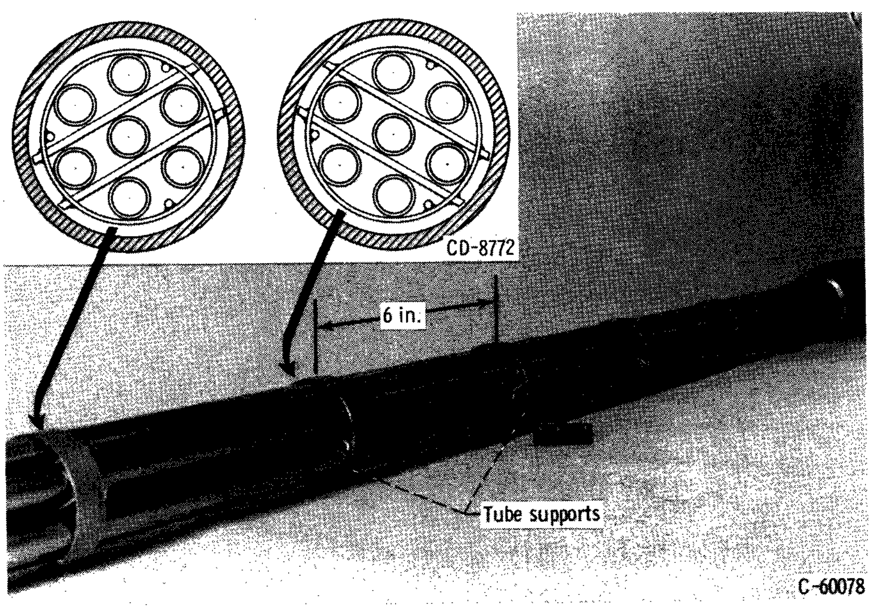


Figure 4. - Tube bundle before installation in coolant shell.

the operation of the system. The heating loop, the boiler, and the vapor pipe connecting the boiler to the condenser were fabricated from a high-temperature cobalt-base alloy. The remainder of the system was 316 stainless steel. The liquid metal NaK (78 percent potassium and 22 percent sodium, by weight) was electrically heated in the heating loop to provide a heat source for the potassium boiler. The boiler consisted of a shell and tube heat exchanger which could produce potassium vapor at temperatures as high as 1600° F with vapor qualities as high as 100 percent. The potassium vapor passed through a 23-foot-long electrically heated pipe which minimized heat losses and mixed the vapor before it entered the condenser. The condenser consisted of a shell and tube heat exchanger, which was cooled by the NaK flowing in the shell. The liquid potassium leaving the condenser was pumped back to the boiler by an electromagnetic pump through an electromagnetic flowmeter and a throttle valve. The condenser was placed about 6 inches higher than the boiler in order to allow for a slight slope between the boiler and the condenser for drainage. The dump tank was mounted below the working loop and was used to store the potassium when the facility was not in operation. The inventory control tank was located above the working loop and served as a reservoir to control the quantity of potassium (inventory) in the working loop during operation. The final heat sink of the facility was the air-cooled heat exchanger in the cooling loop.

Condenser

The condenser consisted of seven 0.444-inch-inside-diameter tubes about 6 feet long that were bundled together inside a shell of 2.07-inch-inside-diameter pipe. The condenser was mounted horizontally. A schematic drawing of the condenser is presented in figure 2. Potassium vapor entered the tubes from a 2-inch pipe and condensed inside the tubes. Liquid potassium was collected at the outlet of the tubes and flowed back to the boiler in a single 0.5-inch-outside-diameter tube. The NaK coolant (78 percent potassium) flowed in the condenser shell in a countercurrent direction. The entire condenser was constructed of 316 stainless steel. The condenser tubes were formed from 0.5-inch-outside-diameter tubing with 0.028-inch-thick walls. The tubes and the shell were bent as shown to allow for differential thermal expansion caused by temperature differences among the individual tubes and between the tubes and the shell. The shell was enlarged at the bend to allow room for the tubes to lengthen. The tubes were flared into the header, welded, and hand filed to produce entrances as round and smooth as possible in order to reduce pressure loss at the vapor inlet. The tube inlet region is shown in figure 3. The tubes were held in alinement in the shell by tube supports placed at 6-inch intervals along the tube bundle. Details of the tube supports are shown in figure 4. The axial location of the supports was maintained by welding them to three

0.09-inch-diameter rods that were welded to the headers. An insulation of 6 inches was applied to the condenser to reduce the heat loss from the shell.

Instrumentation

The condenser was instrumented to measure both the inlet and outlet temperatures of the potassium and the coolant, the shell temperature profile, the potassium inlet pressure, the overall potassium pressure loss in the condenser, the potassium flow rate, and the coolant flow rate.

Temperature. - The temperatures of both the potassium and coolant streams were measured with thermocouples spot-welded to the pipe walls. The shell axial temperature profile was measured at two circumferential locations, as indicated in figure 2. The thermocouples on the horizontal centerline were spaced 6 inches apart and those at a 45° angle up from the centerline were spaced about 2 inches apart. The first thermocouple was 4 inches from the tube inlet. All of the wall thermocouples were constructed of 20-gage Chromel-Alumel wire with the Instrument Society of America special limit of error. The thermocouple junction was spot-welded to the pipe wall and the wires were insulated with two-hole ceramic beads which were strapped to the pipe for support.

At the potassium inlet end of the condenser, a thermocouple was installed to measure the temperature of the vapor in the center of the stream about 6 inches ahead of the tubes. A Chromel-Alumel thermocouple was swaged into a 1/16-inch-outside-diameter insulated sheath and pushed into a thermocouple well. The well was constructed of 3/8-inch-outside-diameter tubing bent to provide about 2 inches of straight tubing in line with the flow and closed at the end.

The overall coolant temperature rise was measured with a differential thermopile to improve the accuracy of the heat balance around the condenser. Four thermocouple circuits each composed of Chromel-Alumel junctions spot-welded to the coolant inlet and outlet pipes were connected in series to produce four times the output of a single

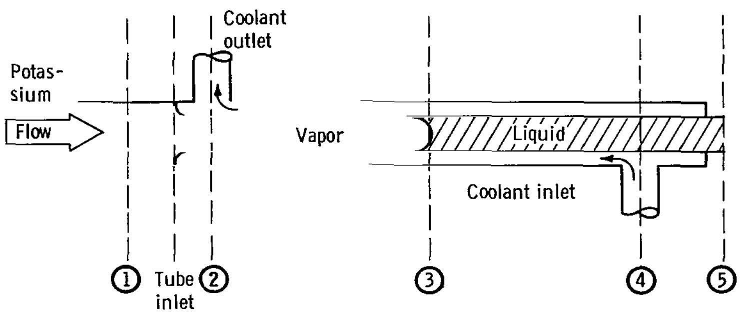


Figure 5. - Instrumentation station locations.

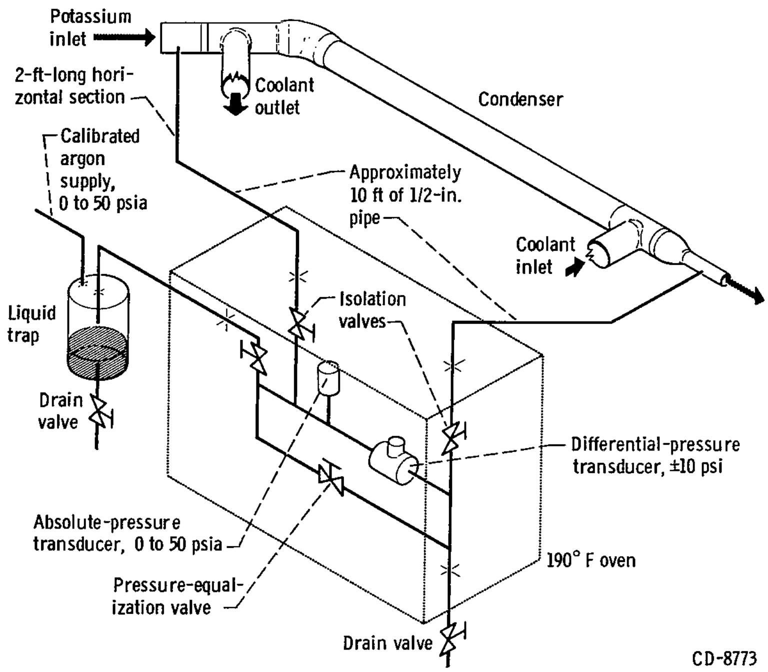


Figure 6. - Schematic diagram of pressure measuring system.

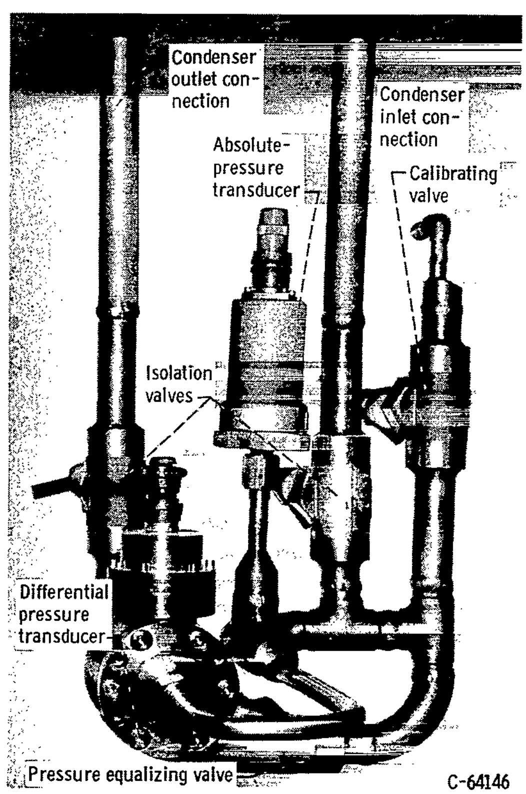


Figure 7. - Installation of pressure transducers in oven.

thermocouple. The output of the thermopile was read with a manually balanced precision potentiometer.

Pressure. - The potassium inlet static pressure (station 1, fig. 5) was measured with a strain-gage transducer with a full-scale range of 0 to 50 pounds per square inch absolute. The potassium overall static pressure drop (stations 1 to 5) was measured with a differential pressure transducer with a full-scale range of ±10 pounds per square inch differential. The transducers were rated for use with corrosive fluids at temperatures below 200° F. Since the transducers and the connecting piping were filled with liquid potassium during operation, they had to be heated to a temperature above the freezing point of potassium (140° F). The transducers and as much of the connecting piping as possible were installed in an oven regulated to maintain 190° F. The remaining piping (about 10 ft of 1/2-in. pipe on each leg) was trace-heated to about 400° F. A schematic diagram of the pressure measuring system is presented in figure 6, and a photograph of the inside of the oven is shown in figure 7. Suitable valves were provided to isolate the transducers from the condenser and to connect them to an argon pressure source so that the calibrations of the transducers could be checked at any time during operation. The connecting lines were welded to the condenser on the horizontal centerline. A 2-foot horizontal run of connecting line was provided adjacent to the condenser to ensure that the liquid-vapor interface in the connecting line would lie at a known elevation above the transducers. In this way, the static head of the liquid potassium above the transducers could be calculated.

The pressures were recorded on strip-chart recorders. The overall expected error of the pressure measuring system was ±0.2 pound per square inch for both the potassium inlet pressure and the potassium pressure drop of the condenser.

Flow rate. - The potassium and coolant flow rates were measured with electromagnetic flowmeters installed in the respective liquid-carrying pipes. A complete description of this type of flowmeter and the equations needed to calculate the flow rate are contained in reference 10. The magnetic field strength of the flowmeters was measured before and after operation of the facility and was found to be the same.

PROCEDURE

The facility was operated continuously for a 2-week period to obtain the data presented herein. The following procedures were followed.

Filling - Starting

The heating and cooling loops were initially filled with Nak and the working-loop dump tank was filled with clean potassium. The working loop was evacuated to a pressure of about 50 microns of mercury in order to minimize the presence of noncondensible gases, and the working loop was heated electrically to about 400° F. The dump tank was pressurized with argon gas, the dump valve was opened, and liquid potassium was forced into the system. When potassium appeared in the inventory control tank (fig. 1, p. 3), filling was terminated by closing the dump valve. The dump valve was kept closed during all subsequent operations. The liquid metals were then circulated in all three loops while the temperatures were being raised to operating levels. When the temperature of the potassium reached about 1000° F, the electric heaters in the working loop were turned off. The system pressure was maintained at a level high enough to prevent boiling by pressurizing the inventory control tank with argon gas. Some data were taken during the liquid circulation period to determine the heat loss from the condenser shell. Samples of the potassium were withdrawn from the loop, and an analysis showed less than 5 parts per million of oxygen. The method described in reference 11 was used for this analysis.

The transition from liquid to two-phase operation was accomplished by first heating the liquid to the operating level and then reducing the pressure in the inventory control tank until saturation conditions were reached in the boiler. As vapor was generated in the working loop, liquid potassium was displaced from the loop into the inventory control tank. At no time were noncondensible gases allowed to enter the system.

Range of Conditions

The independent variables included in this investigation were potassium flow rate, potassium inlet temperature, coolant flow rate, and coolant inlet temperature. The effects of these variables on the dependent variables (such as condensing length and overall condensing pressure loss) were determined by operating the condenser at potassium inlet temperatures of 1400° and 1500° F with potassium flow rates of 300 and 500 pounds per hour as indicated in table I (sets 1 to 8). The data at the potassium inlet temperature of 1400° F (sets 1 to 6) were obtained in two ways. Sets 1 to 3 were run at constant coolant flow rates and variable coolant inlet temperatures. Sets 4 and 5 were run at a constant coolant inlet temperature and variable coolant flow rates. The data with a potassium inlet temperature of 1500° F (sets 7 and 8) were obtained with constant coolant flow rates over a range of coolant inlet temperatures.

The fluid inventory in the working loop had to be adjusted in order to hold both the potassium flow rate and the potassium condenser inlet temperature constant for each set while the coolant flow rate and temperature were varied (sets 1 to 8). At a constant potassium flow rate and a constant coolant flow rate and coolant inlet temperature, the potassium temperature at the condenser inlet could be raised or lowered by increasing or decreasing the fluid inventory of the working loop as indicated in reference 12. For each data point in sets 1 to 8, the coolant flow rate, coolant inlet temperature, and potassium flow rate were set first. Then the isolation valve between the inventory control tank and the working loop was opened. The tank was either pressurized or evacuated to increase or decrease the inventory of the working loop; this procedure set the required temperature (pressure) of the potassium at the condenser inlet. The isolation valve was closed when the desired potassium temperature was reached and was kept closed while the data were recorded.

Some additional data were obtained covering the potassium inlet temperature range from 1200° to 1300° F (sets 9 to 12). These data were obtained with a single fixed inventory in the working loop. That is, the isolation valve between the inventory control tank and the working loop was held closed while the coolant flow rate, coolant inlet temperature, and potassium flow rate were varied.

Before a data point was recorded in either mode of operation, conditions were allowed to stabilize until no change could be observed for at least 15 minutes. Approximately 5 minutes were required to record all the data for each point.

RESULTS AND DISCUSSION

The variable-inventory data are presented in table II and the fixed-inventory data in table III. The symbols used are defined in appendix A, and the methods of calculation are given in appendix B.

The independent variables included in this investigation are potassium flow rate, potassium inlet temperature, coolant flow rate, and coolant inlet temperature. The effects of these variables on the coolant temperature profiles, the condensing length, and the overall pressure loss in the condenser are presented in succeeding sections. First, however, some typical records that give the measured fluctuations of potassium flow rate, condenser inlet pressure, and condenser overall pressure loss will be used to show the conditions under which the condenser data were obtained.

Pressure Fluctuations

The system could be operated satisfactorily over the range of variables of interest, although conditions in the working loop did fluctuate. Measured pressure fluctuations at the condenser inlet varied from 0 to 22 percent of the mean pressure (table II). Condenser inlet pressure fluctuations were less than 5 percent of the mean for 34 of the 54 runs listed in table II. Some typical pressure and flow records are presented in

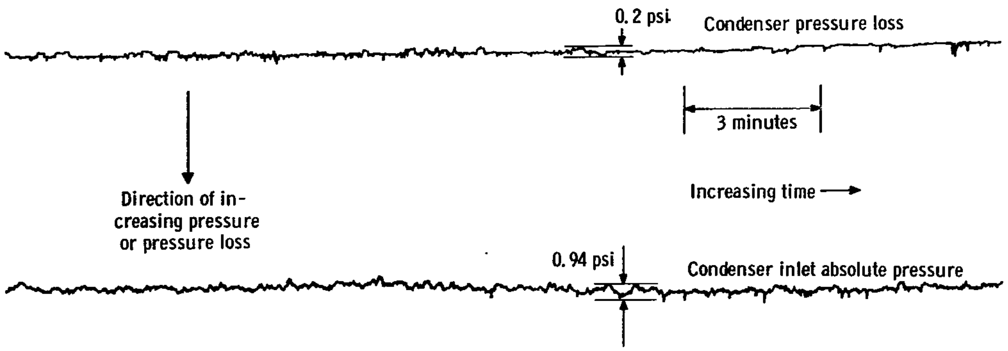


Figure 8. - Typical fluctuations of condenser pressure loss and condenser-inlet absolute pressure. Run 285.

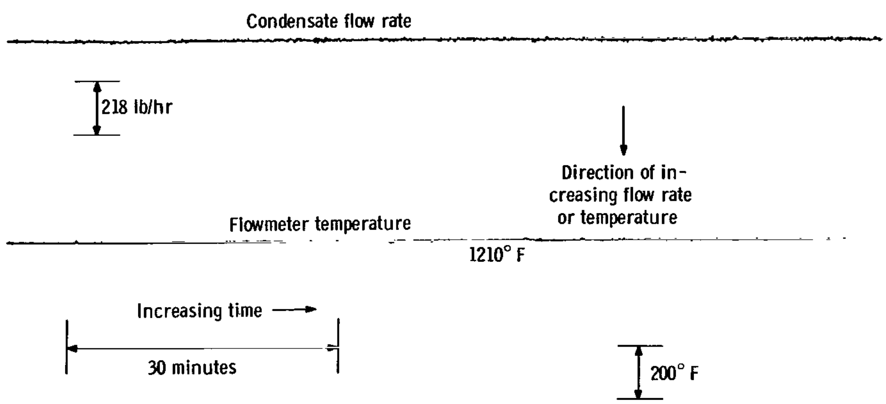


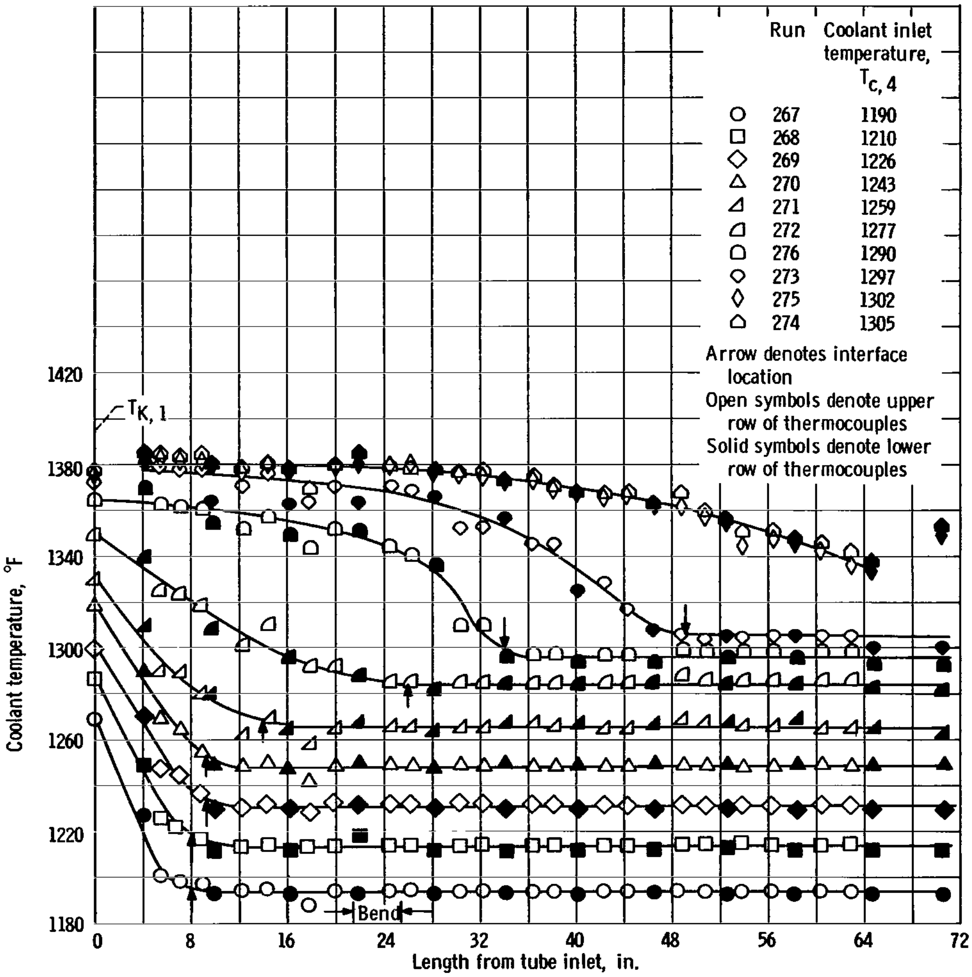
Figure 9. - Typical fluctuations of condensate flow rate and temperature. Run 285.

figures 8 and 9. For the case illustrated, the condenser inlet pressure fluctuated 0.94 pound per square inch (4 percent of the mean), the condenser pressure loss fluctuated 0.2 pound per square inch, and the potassium flow rate fluctuated about 15 pounds per hour. From the available data, it is not possible to determine which component of the system was the primary source of the fluctuations.

Coolant Temperature Profiles

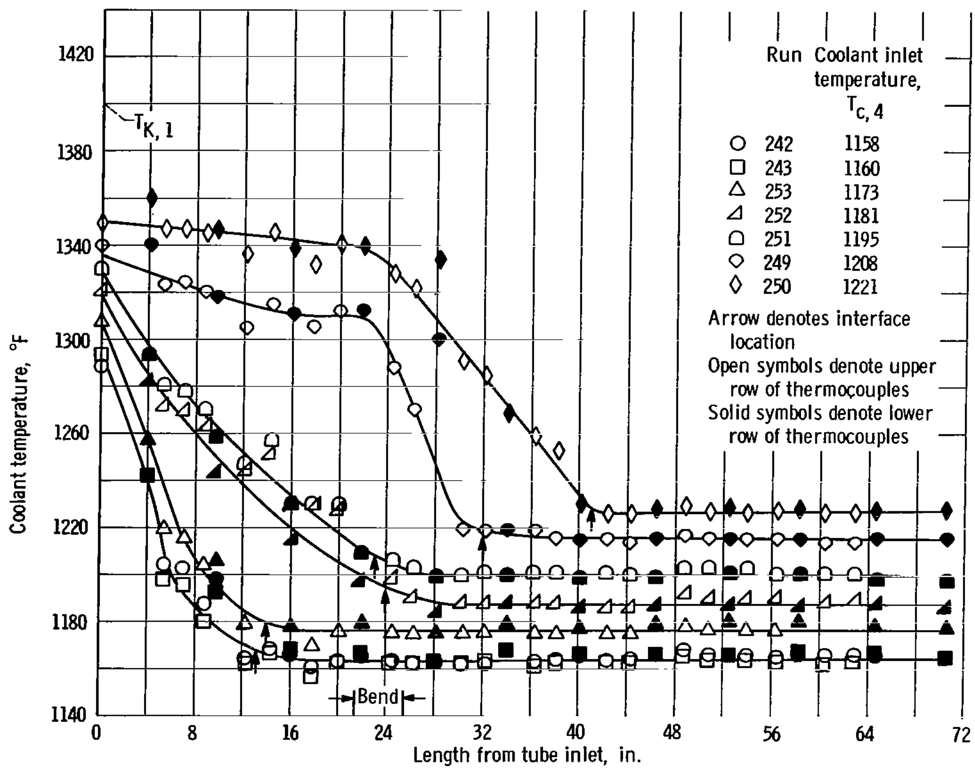
The temperature of the outside wall of the condenser shell was measured at several axial locations and two circumferential positions as indicated in the section APPARATUS. It was assumed that the measured wall temperature was equal to the mean coolant temperature because the heat loss from the condenser (measured during liquid operation) was less than 2 percent of the condensing heat load and because of the high thermal conductivity of the NaK coolant. Coolant temperature profiles for several operating conditions are presented in figures 10 and 11.

The data of figure 10 were obtained with different values of coolant inlet temperature



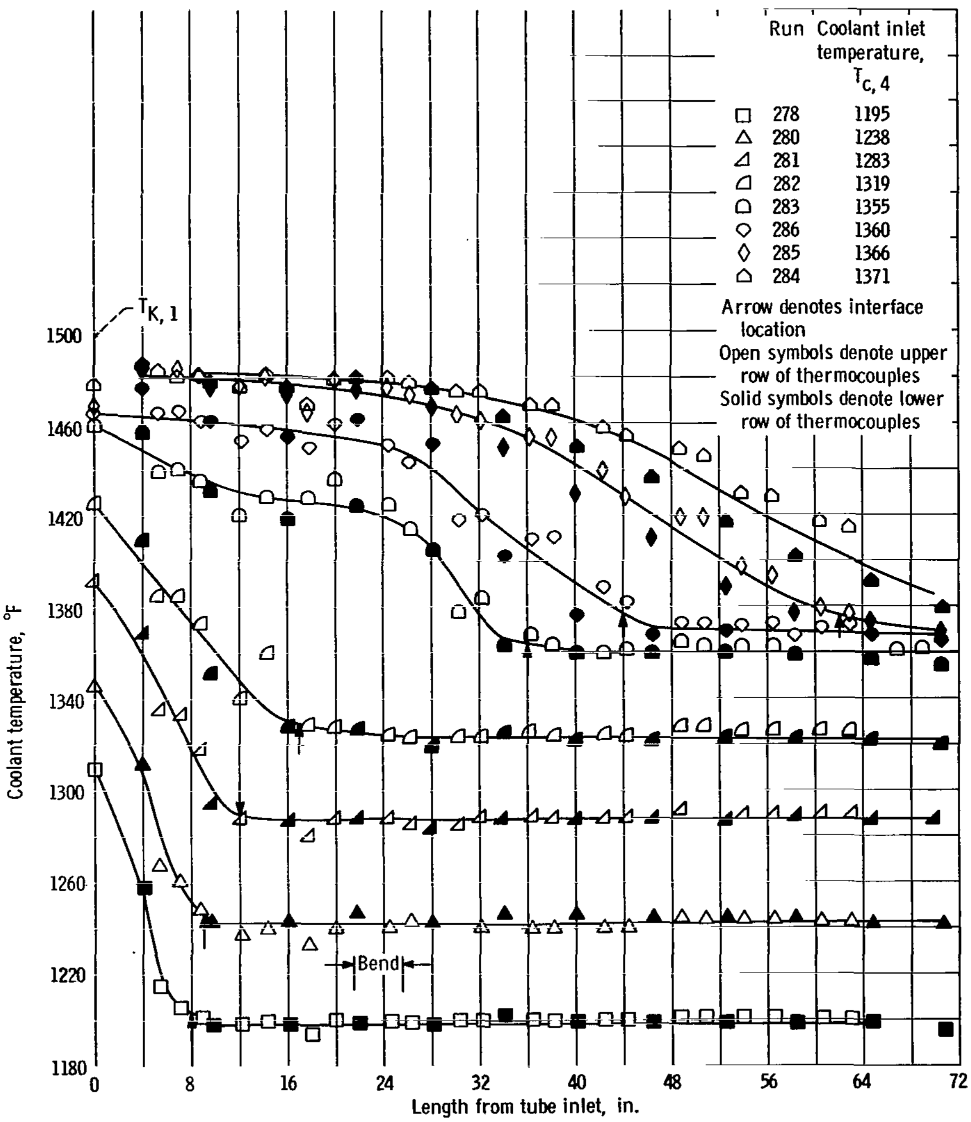
(a) Set 1. Coolant flow rate, 14.3×10^3 pounds per hour; potassium flow rate, 296 pounds per hour; potassium inlet temperature ($T_{K,1}$), 1398° F.

Figure 10. - Coolant temperature profiles for runs at various coolant inlet temperatures.



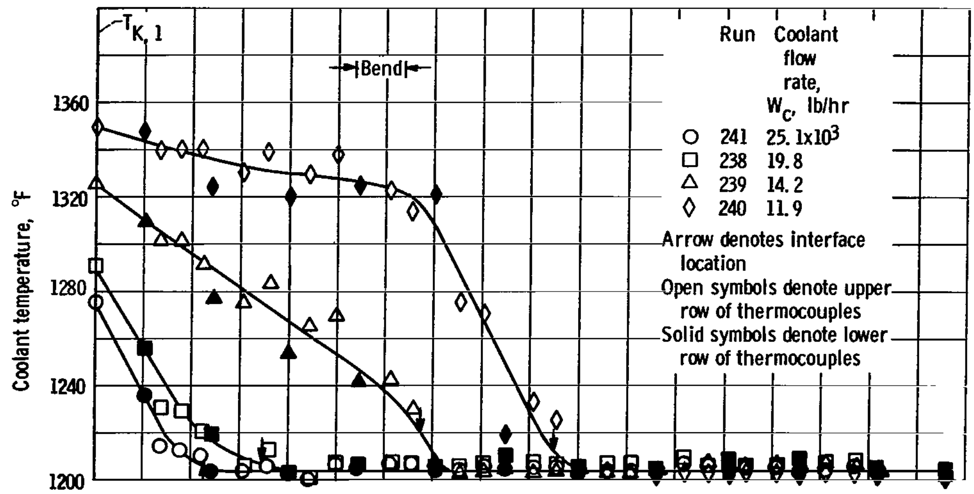
(b) Set 2. Coolant flow rate, 14.2×10^3 pounds per hour; potassium flow rate, 492 pounds per hour; potassium inlet temperature ($T_{K,1}$), 1400° F.

Figure 10. - Continued.

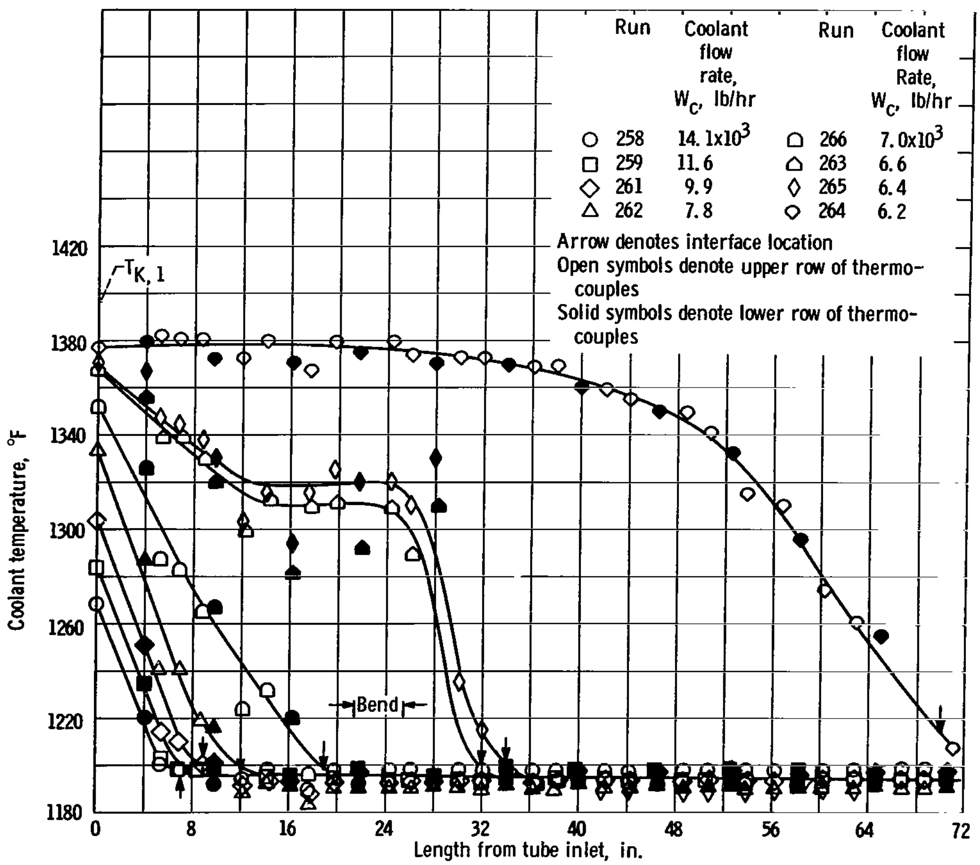


(c) Set 8. Coolant flow rate, 14.3×10^3 pounds per hour; potassium flow rate, 493 pounds per hour; potassium inlet temperature ($T_{K,1}$), 1497° F.

Figure 10. - Concluded.



(a) Set 4. Coolant inlet temperature, 1199° F; potassium flow rate, 489 pounds per hour; potassium inlet temperature ($T_{K,1}$), 1389° F.



(b) Set 5. Coolant inlet temperature, 1189° F; potassium flow rate, 298 pounds per hour; potassium inlet temperature ($T_{K,1}$), 1396° F.

Figure 11. - Coolant temperature profiles for runs at various coolant flow rates.

for each run (sets 1, 2, and 8 of table I), whereas the data of figure 11 were obtained with different values of coolant flow rate for each run (sets 4 and 5 of table I). Each part of these figures contains runs with the same potassium inlet temperature and potassium flow rate. The two rows of shell thermocouples mentioned in the section APPARATUS are indicated separately by the solid and open symbols. The temperatures from the two rows of thermocouples were recorded about 2 minutes apart. In most cases, the two rows of thermocouples gave the same profile, which indicates that conditions did not change during the recording period and that the coolant temperature was the same at the two circumferential locations selected. The location of the liquid-vapor interface was determined by the method of appendix B and is indicated by the small arrow on each temperature profile. In every case, it was observed that the coolant was nearly isothermal to within a few inches of the liquid-vapor interface and that the condensate outlet temperature was within a few degrees of the coolant inlet temperature. These results indicate that for the conditions investigated the liquid condensate subcooled rapidly to the coolant inlet temperature in the region just beyond the interface.

As the coolant outlet temperature approached the vapor temperature, the slope of the coolant temperature profiles near the potassium entrance decreased (figs. 10 and 11), and the condensing length increased for the same vapor flow rate and inlet temperature. This was true whether the coolant outlet temperature was increased by increasing the coolant inlet temperature (fig. 10) or by decreasing the coolant flow rate (fig. 11). When the coolant outlet temperature was very close to the potassium temperature near the inlet end of the tubes (e.g., runs 275, 274, 264), the slope of the coolant temperature profile was very small near the potassium inlet of the condenser. Since the slope of the coolant temperature profile can be related to the rate of heat transfer, it can be concluded that very little condensing occurred in the early portion of the tubes for the runs with high coolant outlet temperature. It is believed that this was caused by a very small temperature difference between the vapor and the coolant in the early portion of the tubes rather than a low overall heat-transfer coefficient. The overall heat-transfer coefficient is composed of the individual heat-transfer coefficients of the condensing side, the coolant side, and the tube wall. The condensing side coefficient is probably greater than 10 000 Btu per hour per square foot per $^{\circ}$F as indicated in reference 2. The coolant-side heat-transfer coefficient was calculated by the method of reference 13 and is presented in table II. For the data of figure 10 (table II, set 1), for example, the coolant-side heat-transfer coefficient was nearly constant with values of about 7000 Btu per hour per square foot per $^{\circ}$F. The heat-transfer coefficient of the tube wall varied only slightly over the temperature range investigated. Values of about 5400 Btu per hour per square foot per $^{\circ}$F are typical of the heat-transfer coefficient of the tube wall. Thus for a given coolant flow rate, such as the data of figure 10, the overall heat-transfer coefficient would be expected to be nearly constant. The variation of the condensing length in figure 10 was obtained by varying the coolant inlet (and therefore the outlet) temperature. The local temperature difference between the coolant and the vapor is not known because the temperature of the vapor inside the tubes was not measured. The temperature of the vapor inside the tubes was lower than the temperature in the upstream pipe because of the pressure drop associated with flow acceleration in the contracted inlet. When the exact pressure is not known, it is difficult to calculate the temperature of the vapor since it is quite sensitive to small changes in pressure. For example, a 1-pound-per-square-inch pressure loss reduces the saturation temperature by 12° F at the 1400° F temperature level. The inlet pressure change is a function of the change due to flow acceleration and the losses due to friction and drag of entrained liquid. The problem is further complicated by the fact that the flow is diabatic and changing phase.

The bend in the condenser tubes started 21.5 inches from the potassium inlet (fig. 2). The runs with the interface just downstream of the bend (e.g., runs 249 and 276) had greater slopes in the coolant temperature profiles in the region just upstream of the interface than did adjacent profiles with longer or shorter condensing lengths (runs 272 and 273). This behavior suggests that the bend was a region of high heat transfer under certain flow conditions. For runs with condensing lengths greater than about 40 inches, there was no great deviation of the coolant temperature profile near the bend.

Heat Flux

The coolant temperature profiles provide a measure of the local heat flux in the condenser. The data from figure 10(a) were reduced to local heat flux as indicated in appendix B by taking the slope of the faired curves. The resulting heat-flux profiles are presented in figure 12. The runs with low coolant temperatures exhibit the characteristic of a high heat flux at the vapor inlet with rapidly decreasing values as the liquid-vapor interface is approached. As the coolant inlet temperature was raised from 1190° to 1277° F, the heat flux decreased, corresponding to the reduced slope of the coolant temperature profiles (fig. 10(a)). When the coolant inlet temperature was

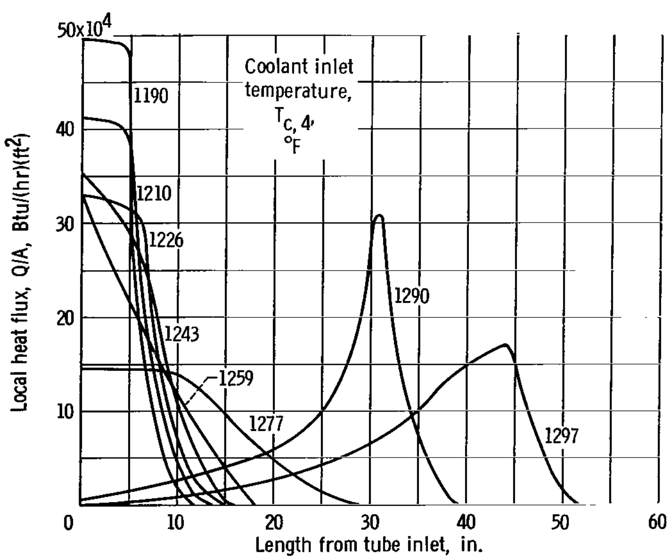
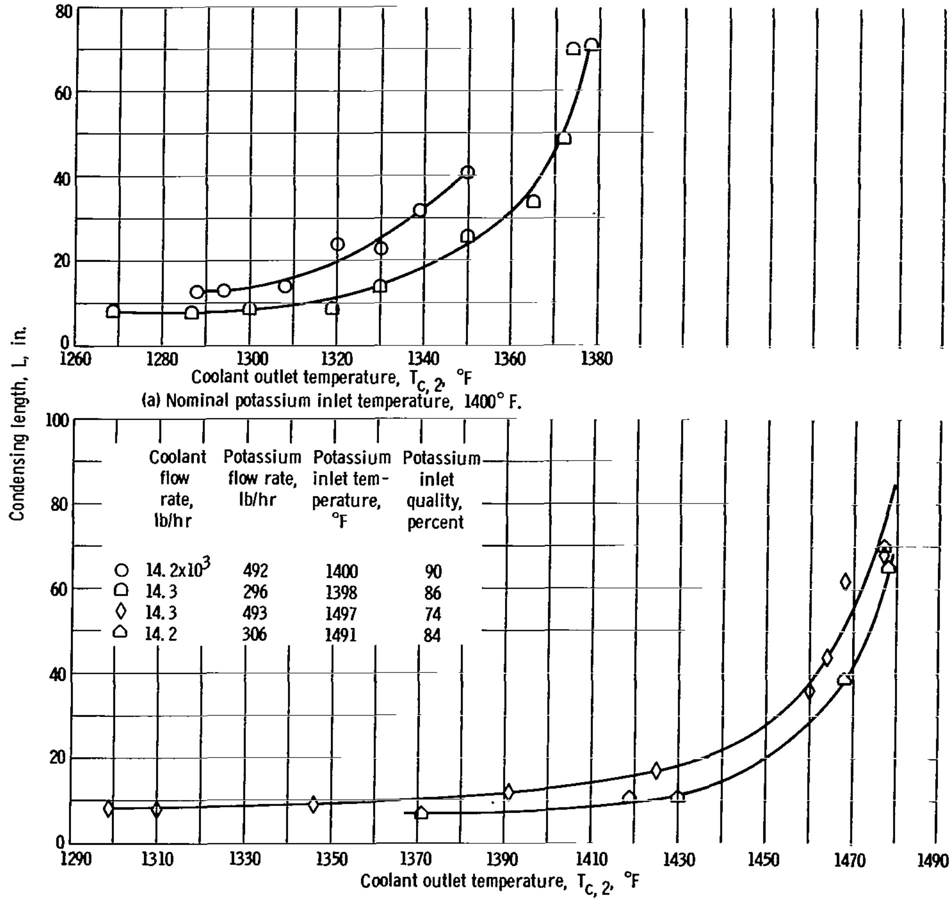


Figure 12. - Heat-flux profiles for runs at various coolant inlet temperatures. Set 1; coolant flow rate, 14.3×10^{3} pounds per hour; potassium flow rate, 296 pounds per hour; potassium inlet temperature, 1398° F.

further raised to 1290° F, however, the heat-flux profile (fig. 12) changed to one with very low values near the potassium inlet and a maximum value near the liquid-vapor interface. The temperature difference between the coolant and the vapor near the potassium inlet was apparently too small to transfer heat at a high rate. This condition was mentioned earlier in the discussion of the coolant temperature profiles. Farther down the tubes, the coolant temperature was lower because of the counterflow arrangement which caused the temperature difference between the coolant and the vapor to be larger, and thus, higher values of heat flux were observed. Close to the liquid-vapor interface, the liquid film on the wall thickened and the vapor velocity decreased, causing a reduction in the heat-transfer coefficient inside the tubes. In addition, the liquid film probably subcooled considerably which lowered the temperature difference across the tube walls. These combined effects caused the heat flux to go through a maximum near the interface and then to decrease. As shown by the coolant temperature profiles, the heat flux decreased to a very low value in the region just beyond the interface, indicating that the liquid potassium subcooled very rapidly. The rapid subcooling of the potassium was the result of the high heat-transfer coefficients available with the liquid metals and the relatively low heat capacity of the potassium condensate.

Mean Overall Heat-Transfer Coefficient

Because the potassium temperature was not measured inside the tubes of this condenser, neither the local overall heat-transfer coefficient nor the local condensing heat-transfer coefficient could be calculated. The mean overall heat-transfer coefficient of the condensing section, tables II and III, was calculated from the measured heat load and condensing length by using an overall log-mean temperature difference between the vapor and the coolant and by assuming that the vapor temperature was constant over the condensing length. The potassium temperature measured in the upstream pipe $T_{K,1}$ was used. The mean overall heat-transfer coefficients for the runs with condensing lengths less than 20 inches are presented in tables II and III. With short condensing lengths, the temperature difference between the vapor and the coolant was large and the assumption of constant vapor temperature could be made without serious error. For long condensing lengths, however, much of the condenser operated with a small temperature difference between the coolant and the vapor. For these conditions, a small reduction in vapor temperature caused by a pressure loss could result in large errors in the log-mean temperature difference and in the calculated overall heat-transfer coefficient. Examination of the data in tables II and III indicates that most of the data for the short condensing lengths have mean overall heat-transfer coefficients between 2000 and 3500 Btu per hour per square foot per °F. The condensing-side heat-transfer coefficient was



(b) Nominal potassium inlet temperature, 1500° F.

Figure 13. - Variation of condensing length with coolant outlet temperature for constant coolant flow rate and two potassium flow rates.

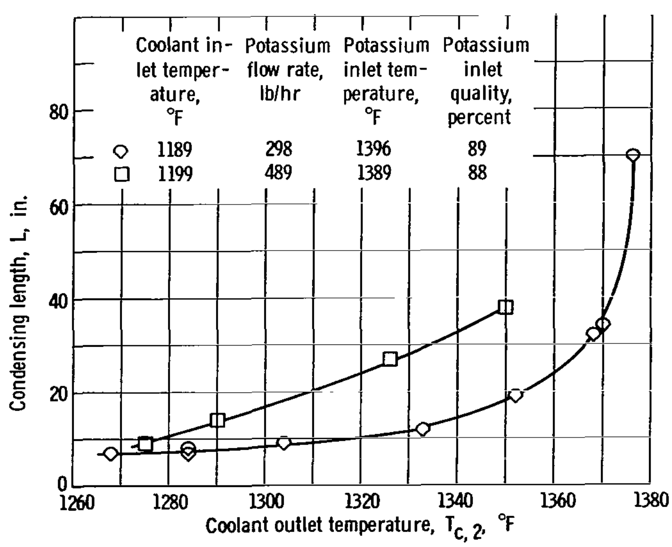
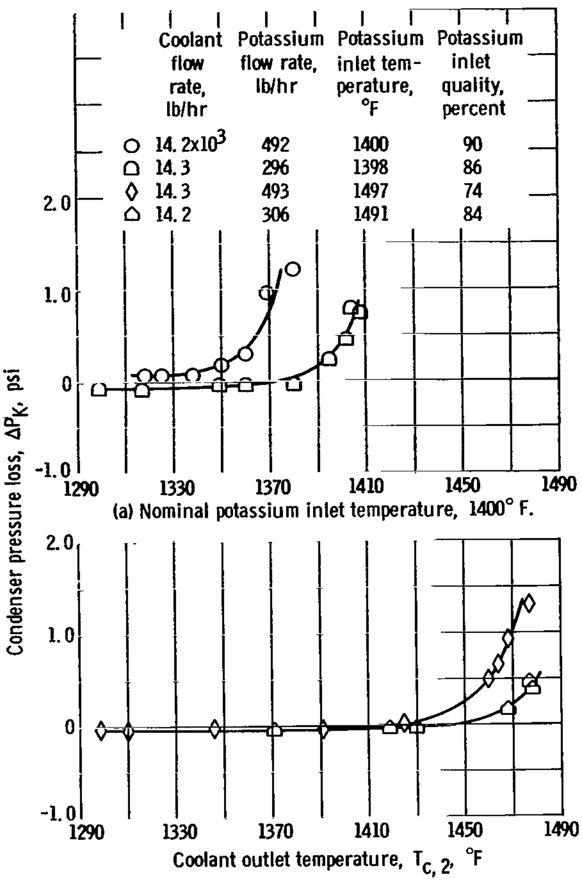


Figure 14. - Variation of condensing length with coolant outlet temperature for a nominally constant coolant inlet temperature and two potassium flow rates.



(b) Nominal potassium inlet temperature, 1500° F.

Figure 15. - Variation of overall condenser pressure loss with coolant outlet temperature for constant coolant flow rate and two potassium flow rates.

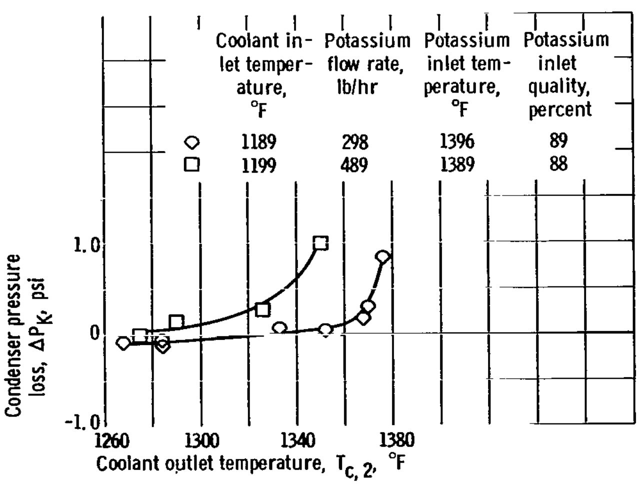


Figure 16. - Variation of overall condenser pressure loss with coolant outlet temperature for a nominally constant coolant inlet temperature and two potassium flow rates.

estimated for this range of overall coefficients by using the resistance of the tube wall and the coolant-side coefficient predicted in the method of reference 13. The mean condensing coefficient varied from about 5000 to 100 000 Btu per hour per square foot per $^{\circ}$F. This range of condensing heat-transfer coefficients is in general agreement with the data reported in reference 2.

Condensing Length

The condensing length was determined from the coolant temperature profiles as shown in appendix B. Condensing length is plotted as a function of the coolant outlet temperature in figure 13. These data were obtained for two potassium flow rates, two potassium inlet temperatures, and one coolant flow rate over a range of coolant outlet temperatures. As the coolant outlet temperature increased, the condensing length increased and became extremely sensitive to small temperature changes. The same result is shown in figure 14 where the condensing length is again plotted against the coolant outlet temperature. For these data, however, the coolant outlet temperature was varied by varying the coolant flow rate with a constant coolant inlet temperature. High coolant outlet temperatures correspond to low coolant flow rates.

Condenser Overall Pressure Loss

The measured overall pressure loss is presented in figures 15 and 16.

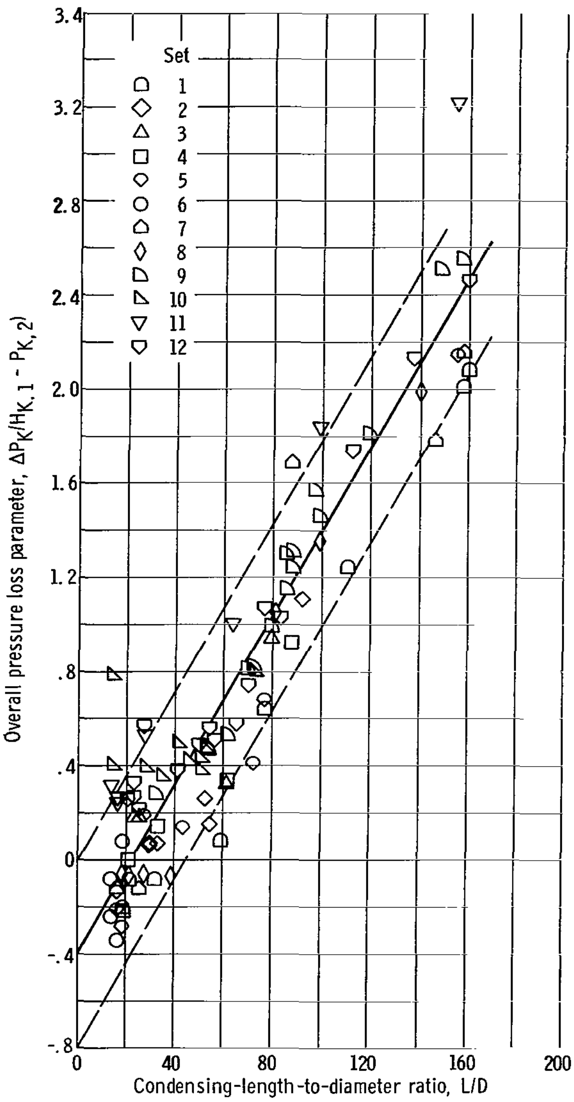


Figure 17. - Correlation of overall pressure loss parameter with condensing-length-to-diameter ratio.

The pressure loss followed the same trends as did the condensing length; that is, it increased with increasing coolant outlet temperature and increasing potassium flow rate. The overall pressure loss was less than 2.5 pounds per square inch for the range of variables investigated.

Most of the volume within the condensing length is filled with vapor because of the large liquid-to-vapor density ratio of potassium, which consequently might be expected to behave much like a single-phase fluid. A correlation of the friction pressure drop in a single-tube steam condenser based on single-phase flow parameters is presented in reference 14. A correlation of the overall pressure drop of the potassium condenser used for the present investigation was obtained by plotting the parameter $\Delta P_K/(H_{K,1} - P_{K,2})$ as a function of the condensing-length to tube-diameter ratio. In this parameter, $H_{K,1} - P_{K,2}$ is the velocity head (total minus static pressure) calculated for the inlet of the tubes if it is assumed there is no total pressure loss in the inlet transition (see appendix B). Correlation of the data on the above basis is presented in figure 17. The data from tables II and III have been included. An equation for the overall-pressure-loss parameter as a function of the condensing-length to diameter ratio is derived in appendix C. Equation (C9) indicates that the slope of the correlation line is 4F. Equation (C6) indicates that the F factor is a function of the fluid properties, the inlet vapor quality, the inlet gas Reynolds number, and the tube diameter. The value of the slope factor F for these data is 0.0045. This value of the factor F is almost equal to the Fanning friction factor for turbulent flow of a single-phase fluid. The value of $\Delta P_K/(H_{K,1} - P_{K,2})$ given by equation (C9) when the condensing length is zero is just K - 1, where K is the inlet total-pressure-loss coefficient. An extrapolation of the mean line through the data yields a value of the loss coefficient K of 0.6. An extrapolation of the data scatter band yields values of K from 0.2 to 1.0.

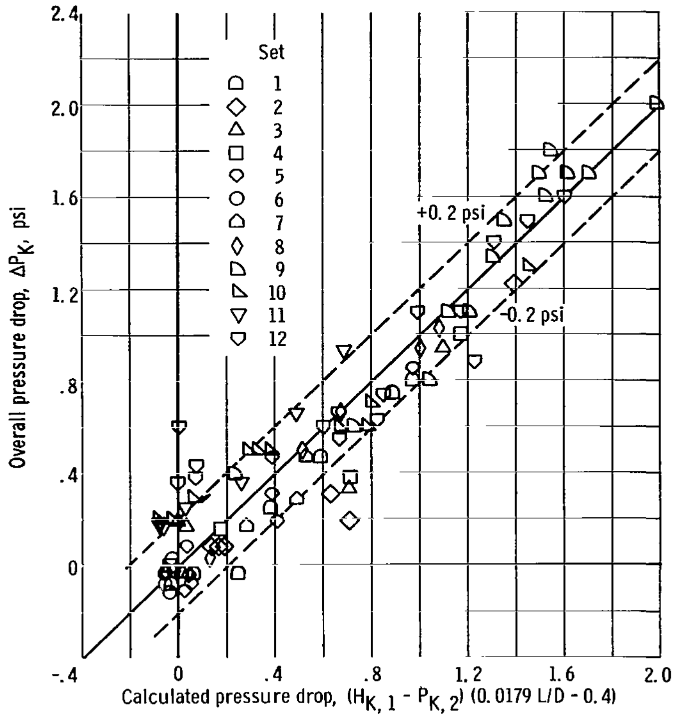


Figure 18. - Comparison of calculated and measured overall pressure loss.

Although the nature of the variation of the coefficient K could not be determined, it can be concluded that the value of K is not a constant for all of the data. In figure 18, the data have been replotted using the slope and mean entrance loss coefficient found from figure 17 so that the magnitude of the data scatter could be measured in pounds per square inch. It can be seen that the bulk of the data fall between lines of ±0.2 pound per square inch. This magnitude of scatter is about the same as the expected error of the pressure measuring system.

CONCLUSIONS

A seven-tube potassium condenser was operated over a range of potassium inlet temperature from 1200° to 1500° F. The variation of condensing length, heat-flux distribution, and overall pressure loss with changes in coolant flow rate, coolant inlet temperature, potassium flow rate, and potassium inlet temperature were investigated. The principal results were the following:

1. When the temperature difference between the coolant outlet and the potassium inlet was greater than about 70° F, the heat flux was high at the potassium inlet end of the condenser (up to 500 000 Btu/(hr)(ft^2)) and decreased in the direction of potassium flow.

2. When the temperature difference between the coolant outlet and the potassium inlet was less than about 70° F, a region of low heat flux was observed near the potassium inlet end of the condenser. For these conditions, the heat flux increased in the direction of flow and reached a maximum value close to the liquid-vapor interface.

3. The condensing length was found to be extremely sensitive to small changes in coolant outlet temperature when either high coolant inlet temperatures or low coolant flow rates were used.

4. The overall pressure loss of the condenser divided by the velocity head in the tube

inlet was found to be directly proportional to the condensing-length to tube-diameter ratio. The constant of proportionality was found to be 0.0045.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, December 1, 1966,
120-27-04-02-22.

APPENDIX A

SYMBOLS

A	area, ft^2
C_P	specific heat at constant pressure, Btu/lb
D	diameter, in.
F	slope factor defined in appendix C
g	conversion factor, 32.2 ft/sec^2
H	total pressure, psia
h	film coefficient of heat transfer, $Btu/(hr)(ft^2)(^oF)$
K	inlet-total-pressure-loss coefficient
K_v	function of inlet quality for viscous turbulent flow
L	distance from tube inlet to end of condensation, in.
P	static pressure, psia
ΔP	static pressure drop, psi
Q	condenser heat load, Btu/hr
R	gas constant, 1544/molecular weight, $ft/^oF$
Re	Reynolds number
T	temperature, ^oF
U	overall heat-transfer coefficient, $Btu/(hr)(ft^2)(^oF)$
V	velocity, ft/sec
W	flow rate, lb/hr
X	two-phase flow parameter (ref. 18)
x	quality
γ	ratio of specific heats
λ	latent heat of vaporization, Btu/lb
μ	absolute viscosity, lb/(ft)(hr)
ρ	density, lb/ft^3
φ	two-phase flow parameter (ref. 18)

Subscripts:

c	coolant
g	gas
K	potassium
l	liquid
sc	subcooler
1,2, 3,4,5	stations (see fig. 5)

APPENDIX B

METHODS OF CALCULATION

Location of Liquid-Vapor Interface

The location of the liquid-vapor interface in the condenser was determined from the coolant temperature profiles. The temperature of the coolant at the interface $T_{c,3}$ was found from a heat balance written around the subcooling portion of the condenser:

$$T_{c,3} = T_{c,4} + \frac{W_K C_{P,K}(T_{K,3} - T_{K,4})}{W_c C_{P,c}} \tag{B1}$$

with $T_{K,3}$ assumed equal to the inlet temperature $T_{K,1}$. The coolant temperature rise in the subcooler was of the order of 5° F; negligible error in the interface location was introduced by assuming that the vapor temperature was constant for these calculations. Properties of potassium and NaK were taken from reference 15.

Vapor Quality

The quality x of the potassium vapor entering the condenser was found by writing a heat balance around the entire condenser. The heat loss from the condenser was neglected since it was found to be less than 2 percent of the condensing heat load. The following equation was used:

$$x = \frac{W_c C_{P,c}(T_{c,2} - T_{c,4}) - W_K C_{P,K}(T_{K,1} - T_{K,4})}{W_K \lambda_K} \tag{B2}$$

where $T_{c,2} - T_{c,4}$ was the value of the coolant temperature rise measured with the thermopile. The $C_{P,K}$ was evaluated at an average potassium temperature of $(T_{K,1} + T_{K,4})/2$, and $C_{P,c}$ was evaluated at the average coolant temperature $(T_{c,4} + T_{c,2})/2$. The latent heat of vaporization λ was evaluated at $T_{K,1}$.

Inlet Velocity Head

The velocity head of the potassium vapor in the tube inlets was calculated by assuming one-dimensional isentropic flow of a perfect gas with no total pressure loss between stations 1 and 2. The total pressure at station 1 was calculated from measured static pressure, the vapor flow rate xW_K, and the wall temperature from the following equation which was taken from reference 16:

$$\frac{H_{K,1}A_1(144)(3600)}{xW_K\sqrt{\frac{R}{g}\left(T_{K,1} + 460\right)}} = \frac{\left(\frac{H_{K,1}}{P_{K,1}}\right)^{1/\gamma}}{\sqrt{\frac{2\gamma}{\gamma - 1}\left[\left(1 - \frac{P_{K,1}}{H_{K,1}}\right)^{(\gamma-1)/\gamma}\right]}} \tag{B3}$$

The ratio of specific heats for potassium vapor was assumed to be 1.4.

The total- to static-pressure ratio at station 2 was then calculated by using equation (B3) with A_2 in place of A_1. The velocity head at station 2 was obtained from

$$\left(H_{K,2} - P_{K,2}\right) = H_{K,1}\left(1 - \frac{P_{K,2}}{H_{K,2}}\right) \tag{B4}$$

Local Heat Flux

The local heat flux was obtained from the measured temperature profiles by taking the slope $\Delta T_c/\Delta L$ of the line faired through the data at several locations along the condensing length. The heat flux Q/A was then calculated from the measured coolant flow rate using

$$\frac{Q}{A} = \frac{144W_cC_{P,c}}{7\pi D}\,\frac{\Delta T_c}{\Delta L} \tag{B5}$$

The outside diameter of the tubes was used.

APPENDIX C

OVERALL PRESSURE LOSS

The overall pressure loss $P_{K,1} - P_{K,4}$ is composed of the pressure change due to the inlet contraction (acceleration), the total pressure loss at the inlet due to friction, the pressure loss in the condensing length due to friction, and the pressure rise associated with the reduction of velocity in the condensing length. Each of these factors can be written in terms of the conditions at the tube inlet (station 2). It is assumed that the velocity at stations 1 and 4 is zero and that the pressure loss in the subcooler is zero. Thus,

$$H_{K,1} = P_{K,1} \tag{C1}$$

and

$$P_{K,3} - P_{K,4} = 0 \tag{C2}$$

The total pressure at the tube inlet is

$$H_{K,2} = P_{K,2} + \left(\frac{\rho_g V_g^2}{2g \times 144}\right)_{K_2} \tag{C3}$$

and the total pressure loss in the inlet is

$$H_{K,1} - H_{K,2} = K\left(\frac{\rho_g V_g^2}{2g \times 144}\right)_{K_2} \tag{C4}$$

where K is the inlet-total-pressure-loss coefficient. Combining equations (C1), (C3), and (C4) gives the static pressure drop due to acceleration and losses at the tube inlet:

$$\frac{P_{K,1} - P_{K,2}}{\left(\dfrac{\rho_g V_g^2}{2g \times 144}\right)_{K_2}} = 1 + K \tag{C5}$$

An approximating equation for the two-phase friction pressure loss over the entire condensing length is derived in reference 17 based on the Lockhart-Martinelli correlation for two-phase, two-component flow (ref. 18). As mentioned in reference 17, the value of the Lockhart-Martinelli parameter X is very small over most of the condensing length, and the curve of φ as a function of X was approximated by a straight line on log-log coordinates. The relations derived in reference 17 can be written as

$$\frac{(P_{K,2} - P_{K,3})_{friction}}{\left(\frac{\rho_g V_g^2}{2g \times 144}\right)_{K_2}} = \frac{4L}{D}\left[\frac{0.477}{x^{0.13}}\left(\frac{\rho_g \mu_l}{\rho_l \mu_g}\right)^{0.13} \frac{K_v}{Re_g^{0.304}}\right]_{K_2} \tag{C6}$$

for the viscous liquid - turbulent gas regime.

For the range of inlet qualities and flow rates included in this investigation, the flow regime at the tube inlet was viscous liquid - turbulent gas as defined in reference 18. If the bracketed term in equation (C6) is, for simplicity, considered to be equal to a multiplier F, the friction pressure loss can be written as

$$\frac{(P_{K,2} - P_{K,3})_{friction}}{\left(\frac{\rho_g V_g^2}{2g \times 144}\right)_{K_2}} = 4F\frac{L}{D} \tag{C7}$$

The pressure rise in the condensing length which resulted from the change in momentum can be written as

$$\frac{(P_{K,2} - P_{K,3})_{momentum}}{\left(\frac{\rho_g V_g^2}{2g \times 144}\right)_{K_2}} = -2 \tag{C8}$$

The overall pressure loss is found by combining equations (C2), (C5), (C7), and (C8):

$$\frac{P_{K,1} - P_{K,4}}{\left(\frac{\rho_g V_g^2}{2g \times 144}\right)_{K_2}} = 4F \frac{L}{D} + (K - 1) \tag{C9}$$

When this expression was evaluated for the experimental data, the velocity head in the tube inlet was calculated by assuming no total pressure loss from station 1 to 2 (see appendix B).

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TABLE I. - NOMINAL OPERATING CONDITIONS

Set	Coolant flow rate, W_c, lb/hr	Coolant inlet temperature, $T_{c,4}$, °F	Potassium flow rate, W_K, lb/hr	Potassium inlet wall temperature, $T_{K,1}$, °F
Variable working loop inventory				
1	14.3×10^3	1190 to 1305	300	1400
2	14.2	1158 to 1221	500	↓
3	29.7	1210 to 1279	500	↓
4	11.9×10^3 to 25.1×10^3	1200	500	↓
5	6.2×10^3 to 14.1×10^3	1200	300	↓
6	13.9×10^3	1200	300	↓
7	14.2	1292 to 1407	300	1500
8	14.3	1194 to 1371	500	1500
Fixed working loop inventory				
9	7.5×10^3 to 24.2×10^3	1090	340	[a]1276
10	14.5×10^3	1090	152 to 448	[a]1268
11	14.5	961 to 1200	200	[a]1222
12	14.5	960 to 1236	330	[a]1272

[a]Value averaged over range of inlet temperatures obtained with selected fluid inventory.

TABLE II. - CONDENSER DATA WITH

Set	Run	Flow rate, W_c, lb/hr	Inlet temperature, $T_{c,4}$, ^oF	Outlet temperature, $T_{c,2}$, ^oF	Overall temperature rise, ΔT_c, ^oF	Temperature rise in subcooler, ΔT_{sc}, ^oF	Flow rate, W_K, lb/hr	Inlet pipe wall temperature, $T_{K,1}$, ^oF	Inlet stream temperature, $T_{K,1}$, ^oF	Outlet temperature, $T_{K,4}$, ^oF
		Coolant side								
1	267	14.3×10^3	1190	1269	77.4	4	301	1395	1400	1191
	268	14.3	1210	1287	76.5	4	298	1399	1401	1206
	269	14.2	1226	1300	74.9	3	298	1395	1400	1223
	270	14.2	1243	1319	75.1	3	295	1400	1394	1240
	271	14.4	1259	1330	71.9	3	296	1399	1403	1257
	272	14.4	1277	1350	72.2	2	291	1399	1403	1276
	273	14.3	1297	1372	73.3	2	297	1399	1403	1296
	274	14.3	1305	1378	70.6	3	296	1399	1403	1380
	275	14.3	1302	1374	73.4	1	296	1398	1400	1335
	276	14.4	1290	1365	74.3	2	297	1395	1400	1286
2	242	14.4×10^3	1158	1288	133.7	7	497	1400	1405	1160
	243	14.4	1160	1293	131.1	7	497	1399	1390	1161
	249	14.0	1208	1339	131.8	6	495	1394	1400	1210
	250	14.0	1221	1350	131.9	6	489	1409	1404	1223
	251	14.0	1195	1330	136.0	6	496	1396	1400	1194
	252	14.1	1181	1320	132.6	7	485	1402	1390	1182
	253	14.0	1173	1308	133.6	7	486	1402	1406	1172
3	244	29.5×10^3	1279	1338	60.0	2	496	1400	1400	1280
	245	29.6	1264	1323	60.3	2	494	1389	1405	1265
	246	29.8	1247	1304	59.2	2	494	1403	1401	1249
	247	29.9	1230	1290	61.5	2	495	1383	1403	1230
	248	29.8	1210	1275	61.5	3	499	1389	1391	1208
4	238	19.8×10^3	1201	1290	93.2	4	494	1394	1395	1201
	239	14.2	1197	1326	128.5	6	490	1399	1390	1200
	240	11.9	1197	1350	153.2	7	485	1390	1405	1198
	241	25.1	1200	1275	72.7	3	496	1373	1405	1200
5	258	14.1×10^3	1191	1268	75.9	4	299	1397	1400	1191
	259	11.6	1191	1284	93.6	5	299	1399	1400	1188
	260	11.6	1192	1284	94.6	5	299	1396	1398	1191
	261	9.90	1192	1304	114.2	6	299	1396	1398	1188
	262	7.78	1187	1333	145.8	7	297	1399	1403	1185
	263	6.61	1190	1368	178.1	8	301	1396	1400	1186
	264	6.20	1186	1376	183.1	8	292	1389	1398	1205
	265	6.35	1187	1370	182.8	8	299	1394	1398	1188
	266	7.04	1189	1352	162.7	8	299	1401	1406	1186
6	254	13.0×10^3	1191	1268	78.0	4	299	1398	1404	1190
	255	14.0	1194	1270	79.8	4	299	1395	1401	1193
	256	14.0	1191	1270	78.0	4	301	1398	1401	1189
	257	14.0	1191	1268	76.0	4	299	1400	1401	1189
7	289	14.2×10^3	1292	1371	77.1	4	312	1491	1501	1287
	290	14.4	1341	1419	74.5	3	307	1489	1500	1337
	291	14.3	1354	1430	73.8	3	303	1489	1512	1352
	292	14.3	1389	1468	72.8	2	307	1495	1505	1387
	294	14.1	1407	1478	69.6	2	304	1492	1502	1403
	295	14.2	1404	1477	70.3	3	306	1490	1500	1471
8	278	14.5×10^3	1195	1310	116.4	9	496	1499	1502	1194
	279	14.5	1194	1299	108.5	9	496	1489	1495	1193
	280	14.4	1238	1346	107.7	8	494	1500	1500	1239
	281	14.3	1283	1391	106.8	6	495	1492	1494	1282
	282	14.3	1319	1425	104.0	5	492	1499	1500	1318
	283	14.2	1355	1460	104.5	4	491	1496	1498	1352
	284	14.3	1371	1477	103.7	4	495	1500	1502	1373
	285	14.3	1366	1468	103.3	4	491	1500	1500	1368
	286	14.2	1360	1464	104.3	4	487	1499	1500	1362

VARIABLE INVENTORY IN WORKING LOOP

Inlet static pressure, $P_{K,1}$, psia	Overall static pressure drop, ΔP_K, psi	Heat load, Q, Btu/hr	Inlet quality, x, percent	Condensing length, L, in.	Pressure drop parameter, $\frac{\Delta P_K}{P_{K,1} - P_{K,2}}$	Peak-to-peak variation of $P_{K,1}$, percent of mean	Peak-to-peak variation of ΔP_K, psi	Overall heat-transfer coefficient, U, Btu/(hr)(ft^2)(^{o}F)	Coolant heat-transfer coefficient, h_c, Btu/(hr)(ft^2)(^{o}F)
	Potassium side								
14.6	-0.08	23.3×10^4	86	8	-0.20	3	0	2770	7288
14.9	-.08	23.1	87	8	-.21	2		2803	7276
14.6	-----	22.5	85	9	-----	2		2674	7246
15.5	-.03	22.6	86	9	-.08	2		3129	7228
14.6	-.03	21.9	84	14	-.08	1		2253	7230
14.9	.03	22.1	87	26	.08	2		----	7207
15.1	.5	22.2	86	49	1.2	2		----	7160
15.0	.8	21.4	85	71	2.1	2	.1	----	7147
14.7	.8	22.2	87	70	2.0	2	.1	----	7155
14.9	.3	22.6	87	34	.64	2	.3	----	7179
13.7	0.08	40.5×10^4	91	13	0.06	16	0.2	2654	7306
14.5	.08	39.9	89	13	.07	20	.2	2667	7308
15.4	1.0	38.9	88	32	-----	12	.7	----	7208
15.4	1.2	39.1	90	41	1.11	19	.9	----	7198
14.3	.3	40.1	91	23	.26	17	.2	----	7223
13.7	.2	39.4	91	24	.15	21	.3	----	7246
14.5	.08	39.4	91	14	.07	22	.1	2606	7249
14.6	0.94	37.5×10^4	86	35	0.94	11	0.7	----	8700
15.6	.33	37.7	87	27	.32	10	.5	----	8728
15.1	.17	37.2	85	11	.18	13	.2	3861	8775
15.6	.19	38.8	89	10	.18	14	.2	4825	8803
14.6	-----	38.6	87	9	-----	13	.1	4448	8817
14.6	0.16	38.9×10^4	88	14	0.14	13	0	2662	7849
14.6	.38	38.4	88	27	.34	12	.5	----	7242
15.4	1.0	38.6	89	38	.92	16	.7	----	6983
14.8	0	38.5	87	9	0	17	.1	4686	8380
14.9	-0.08	22.5×10^4	84	7	-0.21	2	0	3017	7271
14.8	-.05	22.9	86	7	-.13	2		3186	6988
14.6	-.11	23.2	87	8	-.28	0		2559	6989
14.8	-----	23.8	89	9	-----	2		2721	6780
15.2	.08	23.9	90	12	.19	2		2299	6517
14.8	.19	24.9	93	32	.41	1		----	6353
14.7	.85	24.0	92	70	2.14	3	.1	----	6299
14.6	.31	24.5	92	34	.68	1	0	----	6321
15.0	.06	24.2	90	19	.14	3	0	1685	6415
15.6	-0.11	22.8×10^4	85	7	-0.34	--	----	2902	7248
15.3	.03	23.4	88	8	.08	10	0	2515	7251
14.6	-.03	22.9	85	6	-.08	9	0	3302	7252
14.8	-.08	22.3	83	6	-.24	2	0	2964	7253
24.1	-0.03	23.2×10^4	84	7	-0.12	4	0	3218	7155
23.5	-.03	22.8	85	11	-.12	4		2960	7090
23.4	-.03	22.6	86	11	-.12	3		3313	7065
23.9	.17	22.2	84	39	1.69	5		----	6980
24.3	.39	21.0	80	65	1.78	7	.2	----	6929
24.3	.47	21.4	83	70	2.15	7	.4	----	6941
24.4	-0.03	35.5×10^4	79	8	-0.06	2	0	2640	7284
23.3	-.03	33.2	73	8	-.06	3		2460	7298
24.9	-.03	32.8	73	9	-.07	2		2436	7231
23.7	-.03	32.4	73	12	-.06	2		2525	7158
24.7	.03	31.7	73	17	-.07	3		2265	7102
23.9	.50	31.7	74	36	1.05	4	.12	----	7022
24.1	1.30	31.6	73	69	-----	2	.4	----	6989
23.6	.94	31.4	73	62	1.99	4	.1	----	7005
24.4	.66	31.5	74	44	1.35	3	.1	----	7005

TABLE III. - CONDENSER DATA WITH

Set	Run	Flow rate, W_c, lb/hr	Inlet temperature, $T_{c,4}$, ^oF	Outlet temperature, $T_{c,2}$, ^oF	Overall temperature rise, ΔT_c, ^oF	Temperature rise in subcooler, ΔT_{sc}, ^oF	Flow rate, W_K, lb/hr	Inlet pipe wall temperature, $T_{K,1}$, ^oF	Inlet stream temperature, $T_{K,1}$, ^oF
		Coolant side							
9	93	14.5×10^3	1088	1185	97.5	4	345	1267	1269
	94	14.4	1087	1181	94.7	4	356	1261	1262
	95	12.1	1086	1198	116.1	5	345	1271	1273
	96	10.2	1084	1218	133.3	6	334	1279	1281
	97	7.59	1086	1270	187.6	8	333	1315	1326
	98	8.32	1085	1262	171.8	8	350	1312	1331
	99	8.93	1087	1246	158.9	7	336	1295	1310
	100	9.98	1086	1226	140.0	6	333	1285	1306
	101	10.3	1085	1226	135.6	6	344	1286	1297
	102	11.1	1088	1214	129.1	5	345	1280	1290
	103	12.9	1086	1198	108.3	4	338	1265	1272
	104	19.4	1088	1158	68.7	3	338	1251	1254
	105	24.2	1087	1142	55.1	2	342	1249	1250
	106	16.8	1088	1172	-----	3	345	1259	1262
	107	14.5	1086	1183	96.4	4	345	1264	1264
10	108	14.4×10^3	1087	1202	114.4	5	400	1295	1300
	110	14.5	1090	1212	117.6	6	443	1323	1320
	111	14.5	1085	1166	80.4	3	300	1242	1247
	112	14.6	1084	1152	66.8	2	250	1222	1234
	113	14.5	1092	1212	120.9	6	448	1327	1316
	114	14.4	1100	1225	125.0	6	448	1327	1330
	118	14.5	1087	1179	92.7	4	345	1261	1264
	119	14.5	1085	1177	89.1	3	331	1258	1267
	124	15.0	1083	1136	52.0	2	201	1218	1244
	125	14.5	1079	1116	37.9	1	152	1207	1244
11	152	14.5×10^3	961	1018	58.4	3	203	1183	1206
	153	14.3	1101	1155	52.7	1	202	1207	1223
	154	14.6	1200	1250	48.8	1	201	1271	1299
	155	14.7	1150	1202	49.4	1	201	1237	1274
	156	14.4	1178	1230	52.8	1	201	1257	1290
	157	14.3	1016	1073	57.2	2	202	1199	1235
	158	14.5	1051	1108	55.5	2	202	1199	1225
12	127	14.3×10^3	1086	1178	90.9	4	332	1259	1260
	128	14.7	1086	1174	90.3	3	334	1260	1259
	129	14.6	1136	1227	91.5	3	333	1287	1287
	130	14.7	1134	1226	91.3	3	333	1284	1289
	131	14.6	1185	1273	88.4	3	332	1315	1333
	132	14.6	1215	1300	86.8	2	329	1338	1350
	133	14.6	1236	1322	87.2	2	330	1348	1363
	134	14.5	970	1065	96.1	5	336	1235	1240
	136	14.5	960	1058	96.5	6	332	1238	1239
	137	14.4	1008	1100	94.5	5	333	1240	1247
	138	14.4	1046	1138	90.5	4	330	1246	1247
	139	14.5	1089	1178	89.5	3	329	1260	1259
	140	14.4	1103	1193	88.1	3	329	1263	1264
	141	14.4	1112	1200	88.7	3	322	1267	1269
	142	14.4	1123	1213	87.5	3	322	1271	1274
	151	14.3	964	1060	97.1	6	334	1241	1241

FIXED INVENTORY IN WORKING LOOP

Outlet temperature, $T_{K,4}$, ^{o}F	Inlet static pressure, $P_{K,1}$, psia	Overall static pressure drop, ΔP_K, psi	Heat load, Q, Btu/hr	Inlet quality, x, percent	Condensing length, L, in.	Pressure drop parameter, $\frac{\Delta P_K}{H_{K,1} - P_{K,2}}$	Overall heat-transfer coefficient, U, Btu/(hr)(ft^2)(^{o}F)	Coolant heat-transfer coefficient, $h_{c,2}$, Btu/(hr)(ft^2)(^{o}F)
	Potassium side							
1087	6.8	1.7	29.6×10^4	96	38	1.15	----	7385
1087	6.8	1.7	28.7	89	38	1.30	----	7380
1084	7.2	1.3	29.5	95	35	.99	----	7180
1083	7.5	1.5	28.6	95	39	1.31	----	6894
1100	9.2	2.5	29.9	99	70	2.55	----	6561
1097	9.2	2.5	30.0	95	66	2.51	----	6654
1089	8.3	2.0	29.8	98	53	1.81	----	6731
1085	7.8	1.7	29.3	98	44	1.46	----	6863
1084	7.8	1.8	29.3	94	43	1.57	----	6903
1086	7.6	1.6	30.0	97	39	1.24	----	6992
1085	7.1	1.1	29.4	97	32	.82	----	7210
1087	6.6	.6	28.0	92	24	.46	----	7913
1087	6.3	.4	27.9	91	14	.28	2267	8398
1088	6.6	.8	--------	95	27	.53	----	7630
1086	6.9	1.1	29.3	94	31	.81	----	7386
1087	8.3	1.3	34.4×10^4	96	32	0.80	----	7363
1089	9.5	.5	35.7	89	15	.35	2219	7374
1083	6.1	.5	24.4	90	18	.49	1760	7395
1080	5.4	.3	20.4	91	12	.39	2368	7402
1091	9.1	.7	36.7	90	22	.43	----	7374
1100	9.7	.6	37.8	93	22	.38	----	7359
1086	6.8	.6	28.2	91	23	.47	----	7388
1085	6.6	.5	27.0	91	20	.42	1674	7387
1078	5.1	.2	16.3	90	6	.40	3533	7452
1079	4.7	.2	11.5	84	6	.78	2419	7408
956	4.3	0.17	17.7×10^4	95	7	0.24	1927	7453
1094	5.1	.25	15.8	88	12	.53	2606	7373
1198	7.6	.93	15.0	85	69	3.22	----	7324
1142	6.1	.36	15.2	85	28	1.0	----	7378
1170	6.9	.66	15.9	90	44	1.84	----	7319
1013	4.7	.19	17.1	93	6	.32	2691	7409
1048	4.7	.16	16.9	93	7	.27	3250	7421
1087	6.7	0.66	27.3×10^4	91	24	0.56	----	7371
1086	6.8	.6	27.7	92	22	.49	----	7407
1136	7.9	1.1	28.1	95	37	1.03	----	7368
1133	8.1	1.1	28.1	95	34	1.07	----	7374
1185	9.6	1.4	27.2	93	50	1.74	----	7327
1213	10.4	1.5	26.7	92	61	2.13	----	7292
1266	11.6	1.6	26.8	93	71	2.46	----	7264
969	5.9	.4	29.1	94	9	.26	2150	7444
959	5.8	.6	29.3	96	10	.33	1815	7450
1008	5.8	.4	28.5	94	11	.22	2068	7421
1046	6.1	.4	27.2	91	10	.27	2620	7397
1090	6.6	.5	27.1	92	18	.38	1781	7382
1102	6.9	.6	26.6	90	25	.51	----	7369
1111	7.1	.6	26.8	93	29	.58	----	7362
1122	7.3	.7	26.4	92	31	.74	----	7352
965	6.1	.9	28.9	94	12	.57	1528	7418

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